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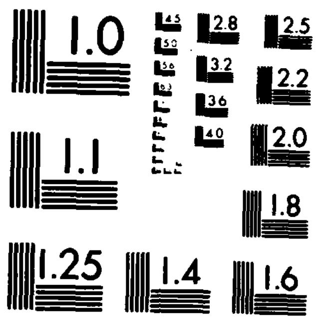

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Report DELNV-TR-0037

AN AUTOMATED SYSTEM FOR CHARACTERIZING LASER PULSES

by

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and

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August 1983

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER DELNV-TR-0037	2. GOVT ACCESSION NO. AD-A138580	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) AN AUTOMATED SYSTEM FOR CHARACTERIZING LASER PULSES		5. TYPE OF REPORT & PERIOD COVERED Final Report January-June 1983
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Leonard A. Atkinson Jay A. Fox		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS ERADCOM, Night Vision and Electro-Optics Laboratory; ATTN: DELNV-L Fort Belvoir, VA 22060		12. REPORT DATE August 1983
		13. NUMBER OF PAGES 42
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report)
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Digitizer
Photon drag detector
Pyroelectric detector
TEA Laser
Power Measurements

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

An automated data acquisition system consisting of a Photon drag monitor, pyroelectric detector, digitizer, and computer is used to accurately and reproducibly calculate laser pulse peak intensity as well as many other important parameters including energy and pulse lengths. This system, along with a working computer program, is explained in detail.

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AN AUTOMATED SYSTEM FOR CHARACTERIZING LASER PULSES

I. INTRODUCTION

1. Subject. This report describes a scheme to calculate laser pulse power, energy, and other parameters by means of a waveform digitizer interfaced with a computer. More specifically, we shall characterize a system which analyzes a pulse emanating from a CO_2 Transversely Excited Atmospheric (TEA) laser. The pulse is detected by a Rofin Model 7441 photon drag monitor, and the waveform is digitized and processed by a Biomation Model 6500 500 MHz-Digitizer and a Hewlett Packard Model 9836 computer, respectively. Although it is this specific system that is described, it is the authors' hope that the techniques utilized will prove to be of general value to laser users. In this spirit, we have included also, a sample BASIC program written for the HP 9836 and shall explain it in depth.

2. Background. In order to produce a better TEA laser or to make performance calculations for existing TEA lasers, it is necessary to have an accurate means of determining pulse intensity and energy. There are several types of commercially available detectors for these applications. We shall describe how two of them (a photon drag device and a pyroelectric detector) can be utilized in an automated data recording and processing system.

The photon drag detector utilized in this experiment is a fast (<1 ns rise time) doped germanium device which produces a voltage proportional to the instantaneous intensity of a laser pulse. This is displayed on an oscilloscope to obtain a record of the temporal history of the pulse. A typical constant of proportionality is given by the manufacturer*, but an exact value depends on beam profile, input intensity, and experimental set-up. It has even been observed that changes in the internal battery supply voltage will affect the constant. Therefore, it is necessary to determine the photon drag constant for each experimental set-up and periodically check this value to update it if necessary.

The pyroelectric detector employed in this set-up is a Laser Precision Model 314 device which is essentially a capacitor formed by depositing metal electrodes on pyroelectric material. When the radiation strikes the coated surface, the heat produced causes a polarization change which gives rise to an output voltage proportional to input energy. The constant of proportionality can be determined by a calorimeter (e.g., Scientech Model 362), and, therefore, this detector can provide a relatively quick means of measuring the laser pulse energy.

Determining the laser pulse energy and intensity with these detectors can be done manually for a single pulse; but for statistically significant numbers of pulses, this method becomes extremely inconvenient at best. We shall describe a practical method of interfacing the photon drag and pyroelectric detectors with a computer to calculate real time pulse energy

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* 714 kW/V for this Model 7441 with a built-in X10 amplifier.

and intensity as well as other parameters concerning the temporal history of the pulse. For example, a typical TEA laser pulse has the intensity profile as shown in Figure 1. A high intensity spike containing 20 to 80 percent of the total energy if followed by a long, low intensity tail. Representative values for the spike half width (FWHM) and the total duration of the pulse are 70 ns and 2 μs respectively. In addition to the intensity and energy, the system described enables the operator to measure the half width, total duration, and amount of energy contained in the spike. If a number of pulses are to be collected, the average and standard deviation of the ensemble energy and intensity can be displayed.

II. THEORY

The following analysis is used in order to find the peak power and energy of the laser pulse. The peak power P incident on the photon drag detector is related to the output voltage V_{pd} by

$$P = K_{pd} V_{pd}, \tag{1}$$

where K_{pd} is the photon drag constant (watts/volt).

The total energy of the pulse E is related to the power by

$$E = \int_0^T P dt, \tag{2}$$

where T is the total duration of the pulse.

Thus,

$$E = \int_0^T K_{pd} V_{pd} dt. \tag{3}$$

If we assume that the incident intensities are low enough so that K_{pd} is independent of time, then the photon drag constant may be expressed as

$$K_{pd} = E/A, \tag{4}$$

where A is the area under the voltage-time curve.

If a pyroelectric detector is used to determine the energy of the pulse, equation (4) becomes

$$K_{pd} = \frac{K_{pe} V_{pe}}{A}, \tag{5}$$

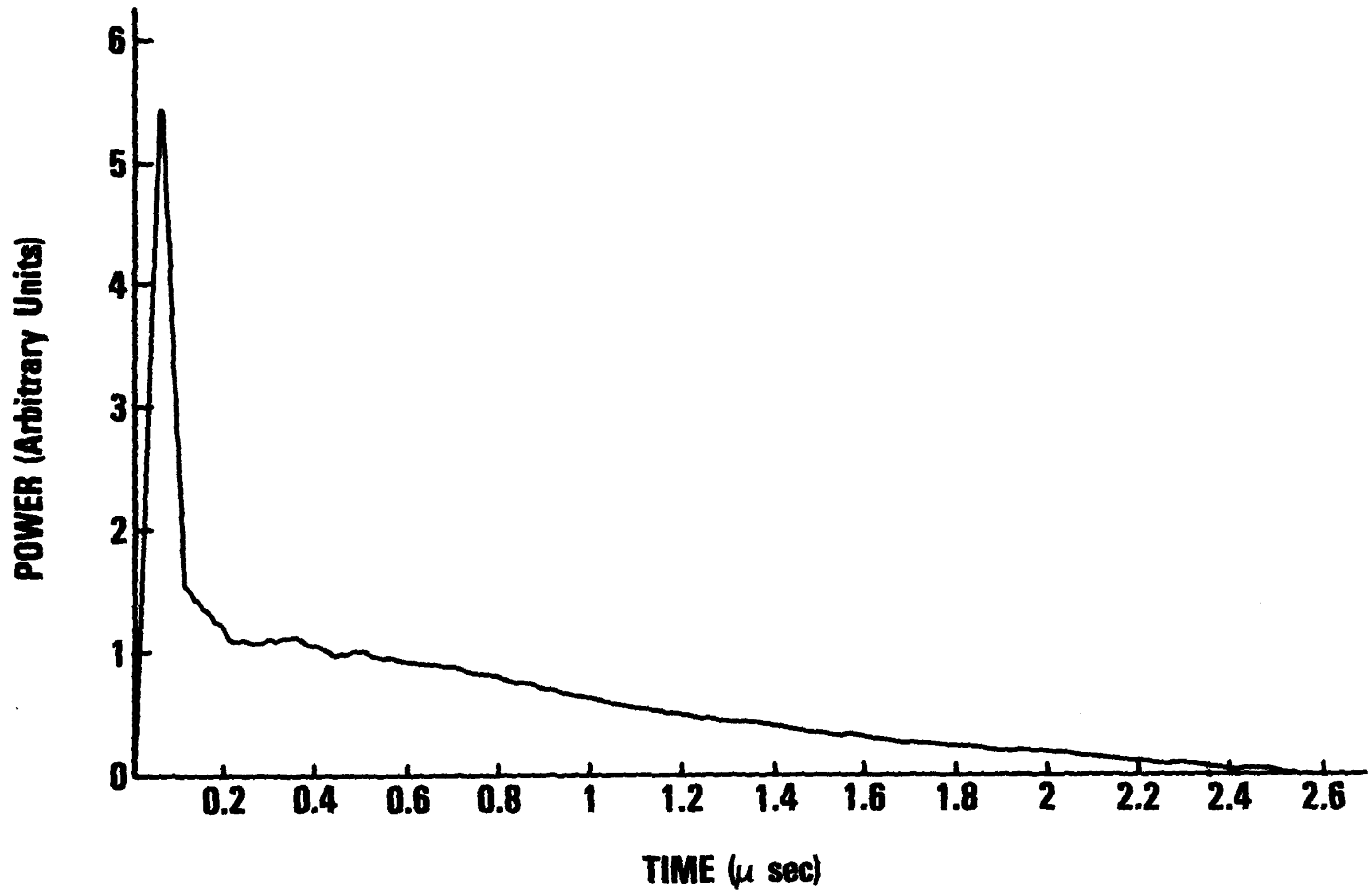

Figure 1. Typical TEA laser pulse.

where

$$K_{pe} = \textit{pyro constant (volts/joule)},$$

and $\qquad V_{pe}$ = maximum voltage produced by laser pulse impacting the pyro detector.

The pyro constant can easily be determined by averaging a suitable number of laser pulses of known energy (e.g., from calorimeter measurements) and by dividing that value by the maximum voltage produced by these pulses. The determination of the area A may be straightforward in principle but in practice may prove to be quite difficult to do accurately. For example, triangular approximations for the pulse are too crude and the presence of a long, low intensity tail that contains a significant portion of the energy makes planimeter measurements, also, inherently inaccurate. It is precisely this consideration that leads one to the choice of digitizing the output of a photon drag detector and using a computer to numerically integrate under the voltage-time curve. At any rate, it is easy to see how the photon drag constant can now be obtained from equation (5) and therefore how the energy and peak power can be measured for any subsequent pulse by the application of equations (3) and (1) respectively.

II. EXPERIMENTAL SET-UP

Figure 2 illustrates the arrangement of the apparatus schematically. The TEA laser is of conventional design and is preionized by means of an array of sparks. The Rogowski-profiled electrodes are separated by a gap of 1 cm and are approximately 11 cm long by 3 cm wide. When this device is fired by means of a spark gap discharging a 10-nF capacitor charged to 20 to 35 kV, it can produce output energies in the 30 to 150 mJ range and peak powers from 100 to 1000 kW. Note that the photon drag monitor is constructed with an internal beam splitting arrangement that allows part of the incident beam to be transmitted directly to the pyroelectric detector. This allows the photon drag detector to be conveniently calibrated without moving the arrangement. As previously mentioned, the digitizer is a Biomation Model 6500 500-MHz device, and the computer is a Model 9836 manufactured by Hewlett Packard. The digitizer is simply a solid state analog-to-digital converter with a memory. It will record at sample rates up to 2 ns/sample and store 1024 samples (a 6-bit resolution/sample). The interface is a Biomation Model 4880 IEEE 488 coupler that converts the digitizer parallel binary format to an IEEE 488 ASCII format. Implementation of our relatively long and slow BASIC program limits pulse repetition rates to 0.7 Hz or less, but for most applications, this is not a severe restriction.

The biggest problem with this set-up is not directly caused by the digitizer/computer apparatus but, instead, by the device which it is measuring, namely the laser. Because of the nature of the discharge in TEA laser, it is inherently electrically noisy. For many commercial lasers this is no big obstacle since ordinary metal enclosures provide sufficient shielding. However, laboratory breadboarded designs are typically unshielded, and obtaining a

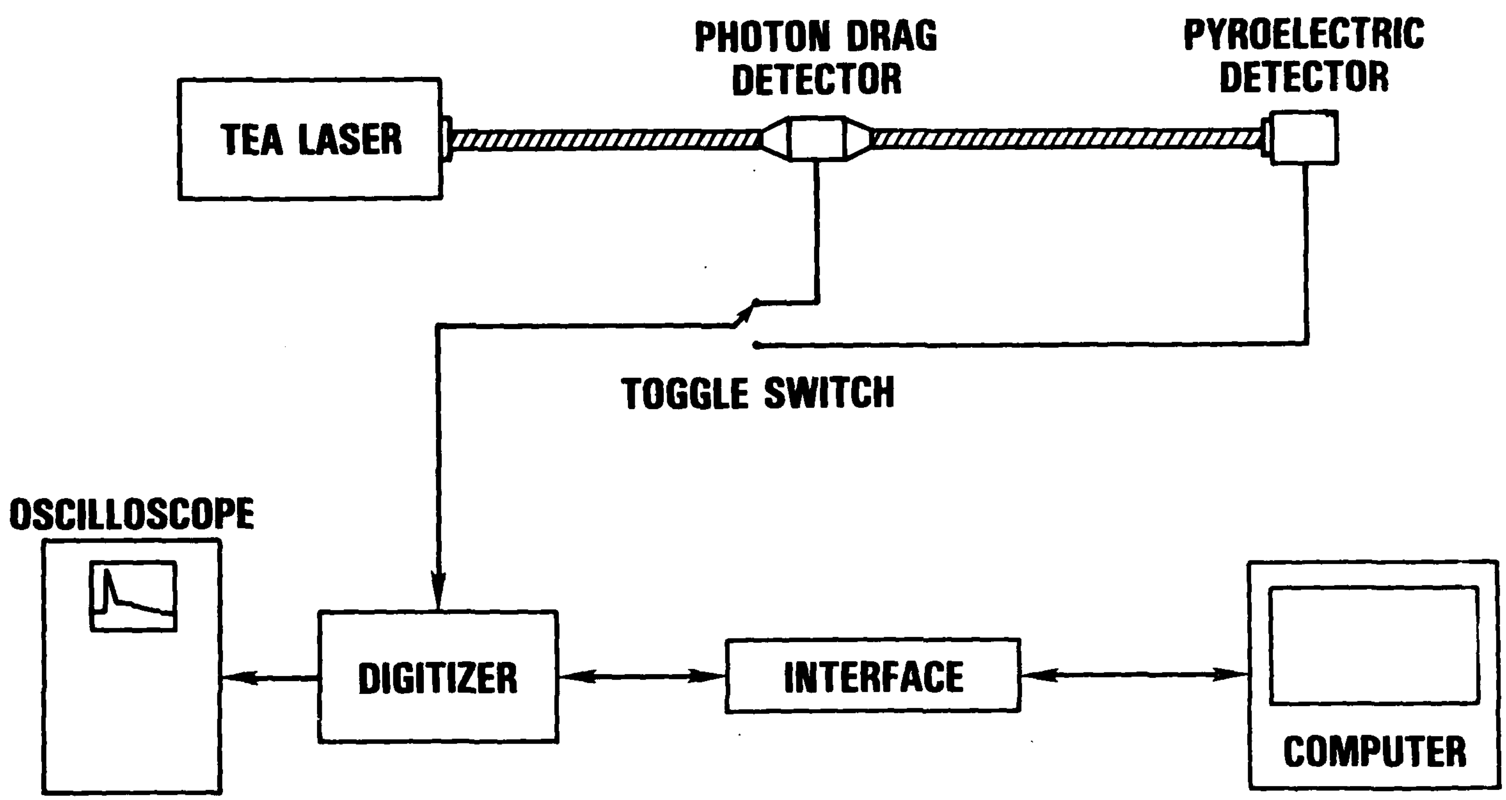

Figure 2. Experimental setup.

favorable signal-to-noise ratio may pose a problem. Shielding a research laser itself may not be practical since circuitry may need to be changed often, currents and voltages must be monitored, and electrical discharges often need to be visually observed. But without shielding, noise levels may be high enough to activate the registers in the digitizer even with no cable connections.

In order to deal with this problem, we have found it expedient to utilize several techniques. First, simply moving the digitizer/computer 3 to 4 m away helped greatly. The extra cable length then required the use of double-shielded coaxial cable. As a further precaution, the box was constructed of plexiglass and lined with copper mesh. When the digitizer and interface were placed inside, the combination of these measures provided sufficient shielding for all except the most severe conditions encountered, when extremely high ($>$ 32 kV) voltages were needed to charge capacitors during certain high pressure experiments. In that case, the pulse forming network was enclosed in a shielded box. Workable signal-to-noise ratios were then restored.

IV. COMPUTER PROGRAM

For the purpose of clarity to both computer programmer and user, two block flowcharts are presented. The first (Figure 3) is a simplified input/output (I/O) flowchart for the user. After the program is running, the user should be able to follow this flowchart with very little knowledge of the algorithms used to determine the output. The second flowchart (see Appendix, Figure A-1) is for the programmer and gives a much more detailed explanation of the algorithms used in the determination of pulse parameters as well as input and output algorithms. Although the program was written in BASIC for the HP 9836 computer and Biomation 6500 digitizer, the calculation algorithms are universal, however. I/O algorithms will probably be different for other systems. A sample computer program listing and output examples are included in the Appendix.

When the program is run, the photon drag constant and pyroelectric constant are set to default values. These initial numbers are not important, because they can be updated after the sample of pulses has been recorded. The digitizer input voltage and time base settings must be entered into the program. This is done automatically by manually arming and triggering the digitizer when it is prompted by the program. The program is now ready for pulse waveform input. When a sufficient number of pulses has been recorded, the user hits Key 0 and the program goes into a calculations mode. The initial data normalization takes about 9 s/pulse. After this, the individual pulse parameters are calculated and printed out on the CRT sequentially. Finally, the average and standard deviation of energy and maximum intensity for the entire sample of pulses are calculated and printed out.

The program is now idling in an output mode and can be continued by depressing the appropriate user defined key. After the corresponding key function is performed, the program returns to the idling point and awaits another key command. The pulses are referred to by

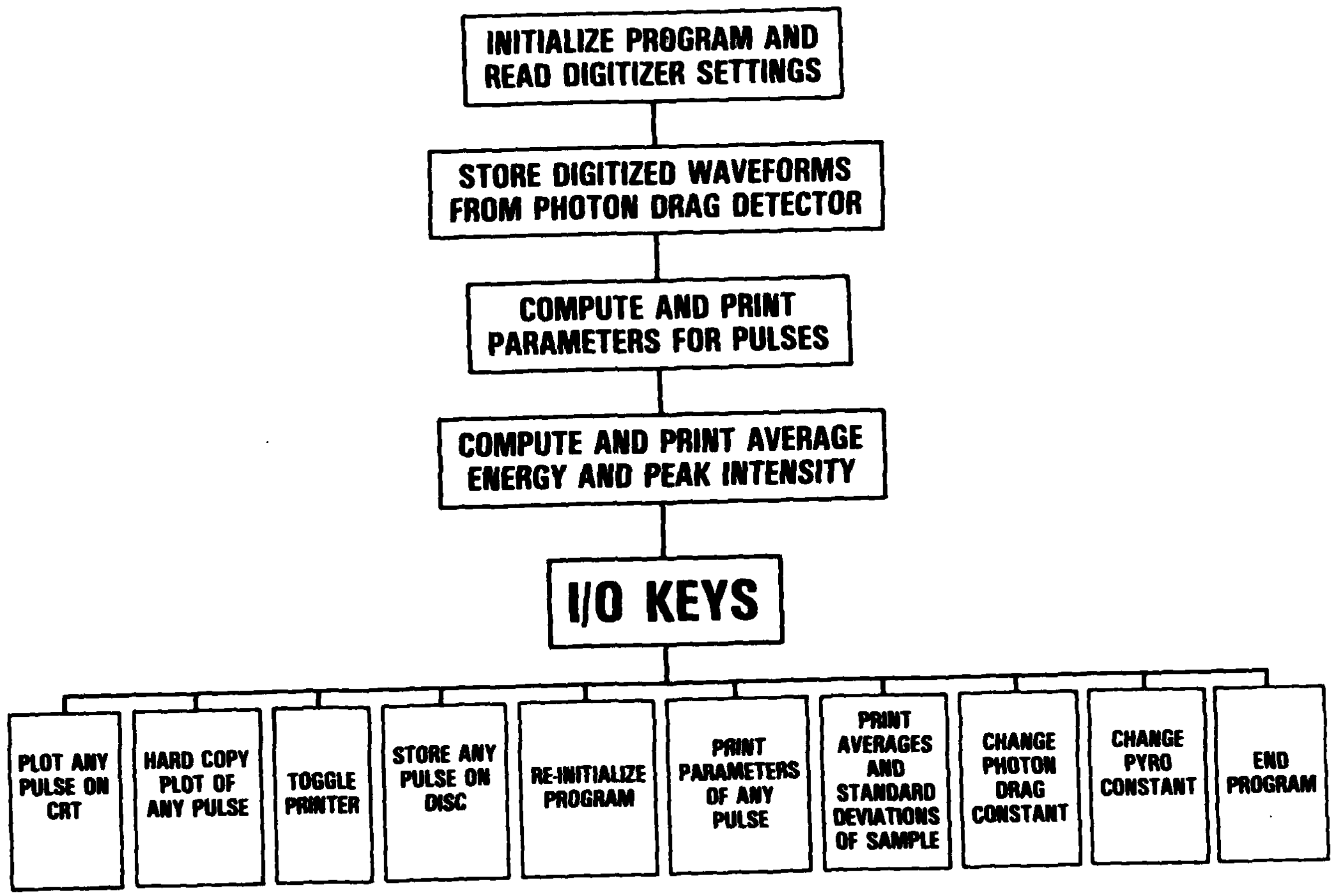

Figure 3. Simplified I/O user flowchart.

number in the sequence in which they were recorded (i.e., the first pulse recorded is No. 1, etc.). Thus, when prompted to refer to a pulse, the operator should be entering an integer less than or equal to the number of pulses in the sample.

A plot of peak power vs. time can be produced on the computer CRT by depressing Key 0. The axes are scaled automatically by the sample intensity. An identical plot can be produced on an external paper plotter by depressing Key 1. A typical output is shown in Figure 4.

If a paper printout is desired, Key 2 is depressed and all further type will be sent to the external printer. If the operator later wishes the type to be printed on the CRT again, depressing Key 2 once more will cause all further output to be displayed on the screen.

A permanent record of any individual pulse may be obtained by pressing Key 3. This enables the user to store a file of pulse intensity on disc, where it can be retrieved later for other analysis.

If the operator desires to measure a new series of pulses, he presses Key 4. At this time, the digitizer sensitivity and time base settings may be changed, if desired. An important feature of this key is that the same values for the photon drag and pyroelectric constants will be retained, whereas they would have been reset to the default values, if the program had been simply started again.

In order to obtain a listing of the parameters for any single pulse, the user need only push Key 5. An example of a typical output can be seen in Figure 5. A printout of the pulse rise time, spike duration, total duration, spike half width, spike energy, total energy, and peak intensity will be sent either to the CRT or to an external printer as specified by Key 2.

Key 6 is used to retrieve the averaged and standard deviation of the energy and peak intensity for the entire collection of pulses. It is important to note that pulses with peak intensities of less than 40 percent of the peak intensity of the series are rejected in calculating this average. This feature prevents the biasing of statistics by false triggering or other random events. However, all pulses, "good" or "bad," are recorded and the information about any one of them is still retrievable even though some are excluded in the averaging process. In addition, the program keeps track of the number of "bad" pulses so that, for example, in an otherwise well-behaved system, the number of laser misfirings during a series of shots can be obtained. This feature has definite utility for those performing laser lifetime tests.

The photon drag constant can be changed so that the average energy of the ensemble agrees with that obtained with either the calorimeter or the pyroelectric detector. (This probably will need to be done after the first run with the default constant.) When the operator presses Key 7, he will be asked whether the energy reading will be done with the calorimeter or the pyrolectric detector. If the reading is obtained with calorimeter, the operator is prompted to enter it via the keyboard in millijoules. If the pyroelectric detector is to be used, the operator is

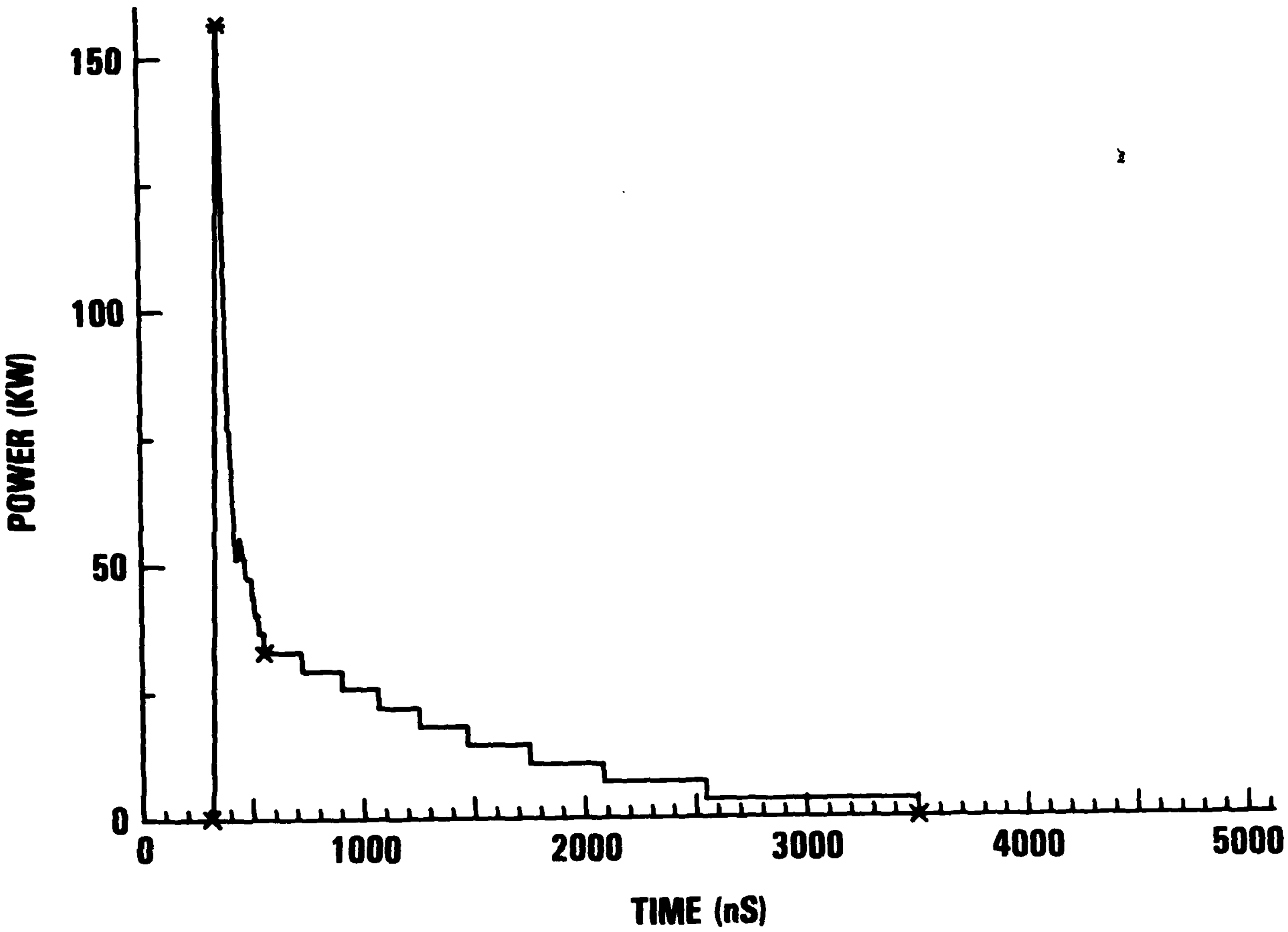

Figure 4. A typical presentation of a laser pulse as seen on the CRT.

PULSE #1 ANALYSIS

PULSE RISE TIME . . . . 45 ns
SPIKE HALF-WIDTH . . . . 55 ns
TAIL DURATION . . . . 245 ns AFTER START OF PULSE
TOTAL DURATION . . . . 3205 ns
SPIKE ENERGY . . . . 15.69 mJ
TOTAL ENERGY . . . . 54.99 mJ
PEAK INTENSITY . . . . 160.7 kW

PULSE #2 ANALYSIS

PULSE RISE TIME . . . . 45 ns
SPIKE HALF-WIDTH . . . . 50 ns
TAIL BEGINS . . . . 170 ns AFTER START OF PULSE
TOTAL DURATION . . . . 3235 ns
SPIKE ENERGY . . . . 12.84 mJ
TOTAL ENERGY . . . . 55.24 mJ
PEAK INTENSITY . . . . 175.3 kW

PULSE #3 ANALYSIS

PULSE RISE TIME . . . . 50 ns
SPIKE HALF-WIDTH . . . . 50 ns
TAIL BEGINS . . . . 265 ns AFTER START OF PULSE
TOTAL DURATION . . . . 3205 ns
SPIKE ENERGY . . . . 16.1 mJ
TOTAL ENERGY . . . . 54.16 mJ
PEAK INTENSITY . . . . 157.1 kW

PULSE #4 ANALYSIS

PULSE RISE TIME . . . . 50 ns
SPIKE HALF-WIDTH . . . . 55 ns
TAIL BEGINS . . . . 115 ns AFTER START OF PULSE
TOTAL DURATION . . . . 3160 ns
SPIKE ENERGY . . . . 10.75 mJ
TOTAL ENERGY . . . . 55.07 mJ
PEAK INTENSITY . . . . 175.3 kW

STATISTICS EXCLUDING BAD PULSES

AVERAGE MAXIMUM INTENSITY = ... 166.9 kW
STANDARD DEVIATION OF INTENSITY = ... 7.9 kW
AVERAGE ENERGY = ... 55.0 mJ
STANDARD DEVIATION OF TOTAL ENERGY = ...5 mJ

*****PHOTON CONSTANT=116.88 PYRO CONSTANT=459.13*****

TOTAL OF 0 BAD PULSES OUT OF 10 RECORDED

Figure 5. Pulse parameter listing.

directed to select that detector via a SPDT switch (see Figure 2) and to fire a number of pulses into it. The average value of the peak voltage is automatically calculated and used to determine the energy of the laser, whereupon this information is used to calculate the new photon drag constant. In either case, all future pulse data will automatically use this updated constant.

In order to use the pyroelectric detector, it is necessary to calibrate it. Pressing Key 8 will facilitate this task. The user is directed to let several pulses impinge on the detector, and as previously stated, the output is averaged. Then, a calorimeter is used to find the actual energy and this value is entered via a prompt. The new pyro constant is displayed and used thereafter.

As indicated in the flowchart (Figure 3), Key 9 is used to end the program. The user should be aware that this key must not be used to simply enter a new series of shots (Key 4 should be chosen for that). Rather, this key reloads the internal disc program directory and, thereby, facilitates the easy transfer to another program.

V. RESULTS

As noted earlier, we have used this instrumentation to measure pulse characteristcs over a wide range of intensities and energies. Generally speaking, the results have been reasonably self-consistent and useful. As an indication of the former, consider the following results. The output from a Marconi T250 TEA laser was measured with the photon drag/digitizer combination. Usually, great pains are taken to ensure optical alignment and rigidity of all components. For example, an optical table and rail are used together with a clamping arrangement that prevents relative motion between the laser under test and the detector. This time, however, we deliberately chose a potentially more unstable configuration to test the sensitivity of this requirement. The laser was set on a lab jack, and the detector was mounted on a simple holder. Neither device was fixed to the table. Four separate measurements of ten shots each were made. After each measurement the detector was removed and replaced before the next set. The positioning was aided by means of a carbon block that sparked when struck by a pulse. No attempt was made to keep the distance from the laser to the detector constant. The measured intensities are given in Table 1.

Table 1. Peak Powers Measured in Four Separate Runs of Ten Shots Each

Trial No.	Power (kW)
1	176.2 ± 5.4
2	172.9 ± 8.4
3	168.7 ± 13.2
4	166.1 ± 11.4

Since the averages are themselves only spread approximately 3 percent about a central of 171 kW, the reproducibility of this method of measurement has been demonstrated.

It should be noted that the first three trials were taken with a digitizer sampling rate of 5 ns channel. This relatively crude measurement was necessary in order to make sure that the entire pulse would be recorded. That is, since the pulse lasted almost 3400 ns, then the fastest setting of 2 ns/channel X 1024 channels would not be sufficient and the next setting (5 ns) had to be used. If one chooses, however, to use the faster setting, no useful information is lost except for the total energy and, of course, the total duration. (Trial No. 4 uses the 2 ns setting.) On the other hand, even using the more coarse setting of 5 ns does not drastically change the time measurements. For example, using the 2-ns setting gave a halfwidth measurement of 50 ± 6 ns while the 5-ns setting yielded 53 ± 6 ns for the same measurements. The results using the digitizer compared favorably with those obtained by analyzing oscilloscope traces; e.g., see Table 2.

Table 2. The Halfwidths and Rise Times of Pulses as Measured With a Digitizer and an Oscilloscope

Time	Digitizer	Oscilloscope
$T_{1/2}$ (ns)	48 ±6	45 ±4
T_{rise} (ns)	47 ±3	43 ±1

The oscilloscope used had a quoted bandwidth of 400 MHz and was a Tektronix 7834 storage device with a 7A19 amplifier and a 7B85 time base. The measurements were made using the 10-ns/div sweep. Digitizer measurements were taken of 40 pulses, while six traces were used for the oscilloscope data. These results indicate that the digitizer can consistently produce measurements that agree with those obtained in a more conventional manner to within 10 percent.

VI. CONCLUSIONS

It has been demonstrated that the combination of a digitizer and computer is useful in analyzing the output of laser pulses. More specifically, we have shown that important pulse parameters including energy, power, half width, rise time and total duration can be measured with reasonable accuracy and consistency. The purpose in doing this is not to suggest that this instrumentation be used in place of other simpler and more conventional measuring devices, but instead to show that for some applications this technology offers a fairly straightforward means of automatically obtaining and processing large quantities of data.

Although this report specifically deals with the Biomation 6500/Hewlett Packard 9836 combination of digitizer and computer, it is hoped that it will be at least of some value to those using different apparatus. Even in that case, a more detailed examination of the computer program might yield useful information to the reader. For that purpose, we have included our BASIC program listing and a short discussion appears in the Appendix.

APPENDIX

This Appendix is a more detailed account of the computer program including a complete flowchart (see Figure A-1) and a program listing (Figure A-2). It is hoped that this will be useful to not only those with the same digitizer/computer combination, but to others who might benefit from exposure to the algorithms for event recognition, energy and intensity calculations, etc. The blocks in the flowchart are numbered sequentially, and further descriptions are keyed to these numbers.

Descriptions of the flow chart blocks follow. The numbers refer to the blocks, line numbers refer to the program listing, and variable names appear in parentheses.

1. Set Constants (lines 70 to 80). The program sets the values of the photon drag constant (Constant) in kW/V and the pyroelectric constant (Pyro-const) in mJ/V. These values are typical but have to be changed for each set-up. They can be changed after pulse waveforms are input, so default values are not important.

2. Read and Decode Digitizer Control Settings (lines 140 to 610).

a. Format. Data input from the 6500 digitizer is in the form of sample elements. There are 1024 time sample elements in a full screen trace, each with a corresponding voltage to create a stepped waveform. The value of each of the 1024 samples can be set from 2 ns to 1 s giving a full screen range of 2048 ns to 1024 s.

There are 252 vertical steps (253 positions) possible for each time sample (−128 to 124). The value of zero is always center screen, the top is always 124, and the bottom is always −128. Each vertical increment is equivalent to 4 steps. The voltage for each vertical increment is determined by the input range setting (Vrange). Since + Vrange corresponds to a value of 124 steps, each increment is (4 steps/124 steps)*Vrange ≅ .03 Vrange. The value of Vrange can be set from .25V to 5V.

There is an offset which moves the O V line within the field of −128 to 124. This offset is set in terms of a fraction of the input range (from −.99 to + .99 x Vrange). The offset progresses in increments of 4 steps (i.e., −.99 to .99 x 124 approximated to the nearest multiple of 4). This is the point of the O V line. An example (Figure A-3) is shown for clarity.

b. Algorithms. The digitizer control settings are encoded in the last three bytes of data read from the digitizer (1024 to 1026). The code definitions are explained in the "Gould Biomation 4880 Interface Operating and Service Manual," page 32. and are reproduced for reference (Figure A-4).

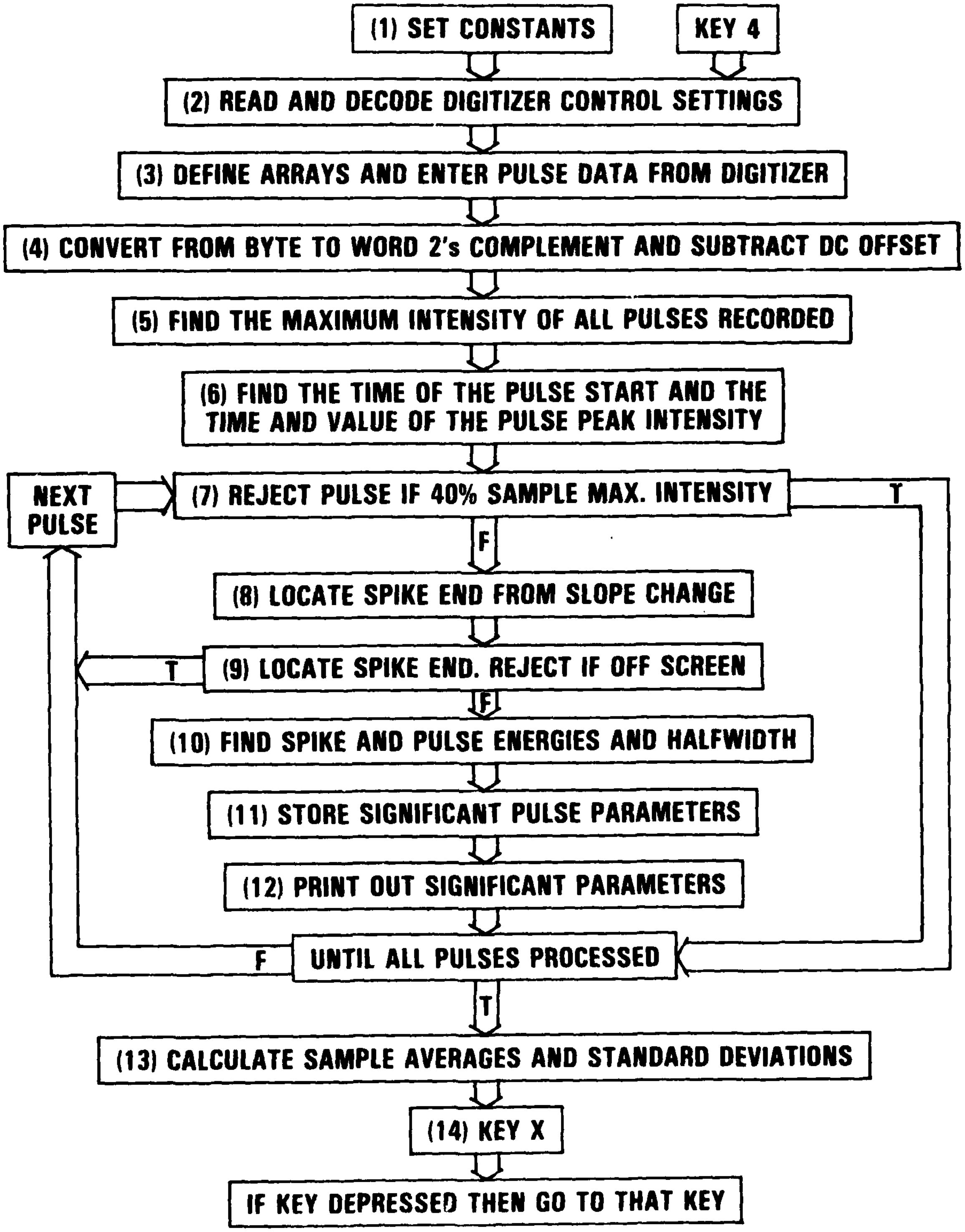

Figure A-1. Complete block flowchart.

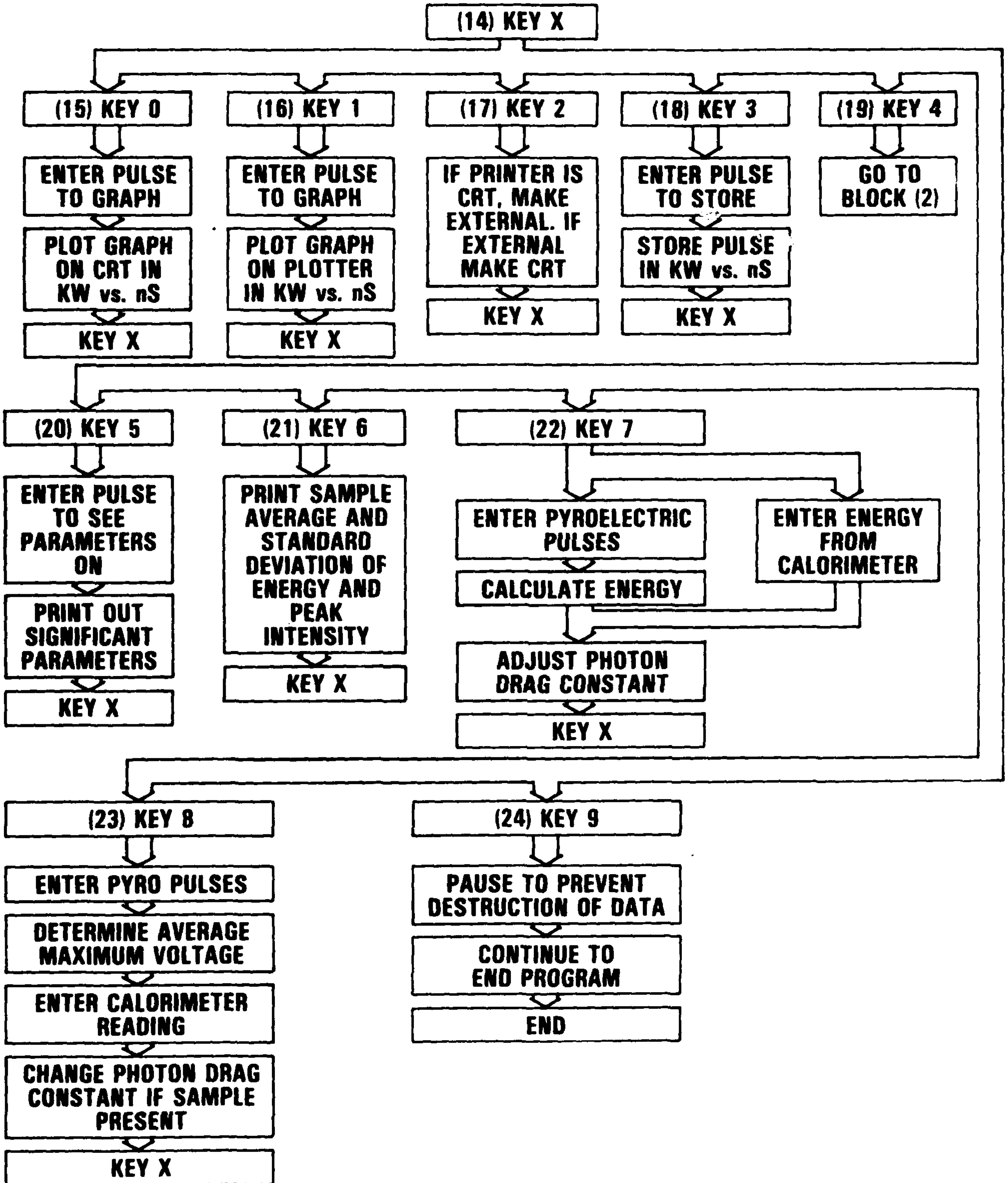

Figure A-1. Complete block flowchart (continued).

A-2. Program listing.

```
        !     LASER PULSE ANALYSIS PROGRAM
        !
        !----------------------------------------------------------------------
20      !     THIS PROGRAM CALCULATES THE INTENSITY VS TIME CHARACTERISTICS, ENERG
        !     AND OTHER PULSE PARAMETERS FROM A  V vs. t WAVEFORM FROM A PHOTON
30      !     DRAG DETECTOR AND AN ENERGY READING FROM A CALORIMETER. THE PROGRAM
        !     INTEGRATES UNDER INTENSITY vs TIME  TO DETERMINE ENERGY
50      !----------------------------------------------------------------------
60      !****** 1) CONSTANT DEFINITIONS AND SETTINGS FROM DIGITIZER *************
*******************************************************************************
70      Constant=999.42    !CONVERSION FACTOR FOR PHOTON DRAG (KW/VOLT)
80      Pyro_const=459.13  !CONVERSION FACTOR FOR PYRDELECTRIC (mJ/VOLT)
81      DISP
90 Start:    GOSUB Off_keys    ! CLEARS KEY FUNCTIONS
100          PRINTER IS 1      ! SETS PRINTER INTERNAL
110          Printer=1
120          PRINT CHR$(12)    ! CLEARS SCREEN
130          GCLEAR            ! CLEARS GRAPHICS
140          GOSUB Settings
150          GOTO 460
160 Settings:PRINT "MANUALLY ARM AND TRIGGER THE 6500 TO RECORD PANEL SETTINGS."
!
170          PRINT "(NO SIGNAL AT INPUT) THEN <CONTINUE>"
180          BEEP 80,.1
190          PAUSE
200          PRINT CHR$(12)      !CLEARS SCREEN
210          OUTPUT 704:11       !PUTS 6500 IN OUTPUT MODE
220          ENTER 704 USING "#,B";B(*)  !LOADS BUFFER ARRAY (UNFORMATTED)
230          OUTPUT 704;0        !CLEARS 6500 OF OUTPUT MODE
240          SEND 7:UNL          !UNLISTEN COMMAND TO ALL UNITS
250          Irnt=B(1024)        !INPUT RANGE NEGATIVE TRUE
260          Opt=B(1025)         !OFFSET POSITIVE TRUE
270          Sint=B(1026)        !SAMPLE INTERVAL NEGATIVE TRUE
280          Weighing=BINEOR(BINAND(Sint,15),15) !MAKES POS TRUE WORD OF NEG TRUE
                                                  BYTE
290          RESTORE 300         !RESTORES DATA (LINE 240)
300          DATA 2,5,10,20,50,100,200,500,1000  ! DATA FOR WEIGHING KEY
310          FOR I=0 TO Weighing
320          ON ERROR GOTO 210
330          READ Interval       !DETERMINES WEIGHING ON SAMPLE INTERVAL
340          OFF ERROR
350          NEXT I
360          Offset=BINAND(Opt,127)*(-1)^(BIT(Opt,7))/100 !DETERMINES FRACTIONAL
                                                           OFFSET FROM BINARY
370          FOR I=2 TO 5
380          IF NOT (BIT(Irnt,I)) THEN 400     ! BRANCHES OUT WHEN BIT IS LOW
390          NEXT I
400          Range=.25*2^(6-I)                 ! VOLTAGE RANGE GENERATION
410          IF I=2 THEN Range=5             !EXCEPTION TO RANGE GENERATION
420          PRINT "RANGE=";Range;"VOLTS"
430          PRINT "OFFSET=";Offset;"X INPUT RANGE(";Offset*Range;" VOLTS)"
440          PRINT "INTERVAL=";Interval;"nS"
450          RETURN !

460     Printer=1             !PROGRAM FLAG TO KEEP TRACK OF PRINTING DEVICE
470     PRINTER IS 1          !SETS PRINTER INTERNAL
480     PRINT "THIS PROGRAM WILL ARM THE 6500 DIGITIZER AND READ THE PULSE DATA"
490     PRINT "AFTER A TRIGGER IS RECEIVED. MAIN MEMORY HANDLES UP TO 120 PULSES"
,CHR$(133)
500     PRINT "PYROELECTRIC CONSTANT=";Pyro_const;"mJ/VOLT"
510     PRINT "PHOTON DRAG CONSTANT=";Constant;"KW/VOLT ";CHR$(128)
```

Figure A-2. Program listing (continued).

```
520     T=TIMEDATE             ! REALTIME SECONDS AT START OF PROGRAM
530     !.................................................................
540     R=ABS(Offset+128)           !CALCULATION OF APPROXIMATE OFFSET TO CHECK
550     Dc_offset=INT(R/4)+4        !          IF THE DIGITIZER HAS BEEN TRIGGERED
560     IF Offset<0 THEN Dc_offset=-Dc_offset      !       CHANGES BACK FROM ABS
570     !..................................................................
580     IF B(500)>=129 THEN B(500)=B(500)-256 !CONVERTS BYTE TO WORD IF NEG.
590     PRINT "DC OFFSET=";Dc_offset,"PIXEL OFFSET=";B(500);"(SHOULD BE WITHIN 4)
"
600     IF ABS(Dc_offset-B(500))>4 THEN 140 ! IF OFFSETS DON'T AGREE RE-TRIGGER
610     Dc_offset=B(500)             ! PIXEL OFFSET IS CORRECT DC OFFSET(USUALLY)
620     INPUT "ENTER OUTPUT OPTION 1)ALL PARAMETERS 2)ENERGY AND INTENSITY ONLY",
Outopt
630     DISP "TURN ON DETECTOR AND <CONTINUE> TO TAKE DATA"
640     PAUSE
650     !*****************************************************************
********************************END OF PARAMETER INPUT*************************
660     DISP " "!_______________ BEGINING OF PULSE INPUT MODE ___________________
________________________________________________________________________________
670     ON KEY 0 LABEL "END INPUT" GOTO Calc    ! ENDS PULSE INPUT MODE
680     PRINT CHR$(12)      ! CLEARS SCREEN
690     PRINT "NOW IN INPUT MODE... READY FOR PULSE INPUT"
700 Main:           !   THIS SECTION USED FOR MAIN MEMORY STORAGE ARRAY
710     PRINT USING "#,-K":CHR$(132),"HIT K0 TO END PULSE INPUT MODE.",CHR$(128)
720     INTEGER A(120,1023),B(1026),Parameter(6,120),Bad_pulse(120)
730     DIM Area(120),Aspike(120),Tempy(1024)
740     Pulse=0                ! NUMBER OF PULSES RECORDED
750     OUTPUT 704:8           ! ARMS THE 6500 DIGITIZER
760     OUTPUT 704:0           ! CLEARS ARM COMMAND
770     OUTPUT 704:11          ! PUT 6500 INTO OUTPUT MODE (SINGLE DIGIT FORMAT)
780     DISABLE                ! DISABLE USER DIFINED KEYS
790     ENTER 704 USING "#,B":B(*)    ! ENTER ARRAY B(1024) UNFORMATTED (FAST)
800     OUTPUT 704:0           ! CLEARS THE 6500 OUT OF DIGITAL OUTPUT
810     Pulse=Pulse+1          ! TALLY OF PULSES ENTERED
820     DISP Pulse;" PULSES STORED "
830     FOR I=1 TO 1023
840     A(Pulse,I)=B(I)     ! MOVE BUFFER ARRAY INTO MAIN ARRAY
850     NEXT I
860     ENABLE                 ! ENABLE USER DEFINED KEYS
870     IF Pulse<120 THEN 750     ! MAIN MEMORY CAN ONLY HANDLE 120 PULSES
880     PRINT "NO MORE ROOM IN MEMORY.  PRESS CONTINUE FOR CALCULATIONS"
890     PAUSE!____________________ END OF PULSE INPUT MODE _______________________
________________________________________________________________________________
900 Calc:!!!!!!!!!!!!!!!!!! CALCULATIONS FOR PULSE PARAMETERS !!!!!!!!!!!!!!!!!!
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
910             OFF KEY 0
920             PRINT CHR$(12)         !CLEAR SCREEN
930             PRINT "IN CALCULATION MODE ......"
940             PRINT "NOW PROCESSING ";Pulse;" PULSES."
950             PRINT USING "-K":CHR$(130),"PLEASE WAIT !!!",CHR$(128)
960             DISP " "
970             Tcalc=TIMEDATE                 !REAL TIME IN SECONDS
980     SEND 7;UNL     !COMMAND UNLISTEN TO ALL UNITS, RESET GPIB ATTENTION LINE
990     Maxval=0       !MAXIMUM VALUE OF ALL PULSES RECORDED
1000    FOR I=1 TO Pulse                      ! LOOP FOR EACH PULSE
1010    FOR J=1 TO 1023                       ! LOOP FOR EACH PIXEL OF EACH PULSE
1020    IF A(I,J)<=127 THEN 1040              !CONVERT TO WORD 2'S COMPLEMENT
1030    A(I,J)=A(I,J)-256                     !         FROM BYTE 2'S COMPLEMENT
1040    A(I,J)=ABS(A(I,J)-Dc_offset)          !ACCOUNTS FOR DC OFFSET ON DIGITIZER
1050    IF A(I,J)<Maxval THEN 1070            !         AND RECTIFIES PULSE
```

Figure A-2. Program listing (continued).

```
1060    Maxval=A(I,J)       !  FINDS THE MAXIMUM INTENSITY OF ALL PULSES
1070    NEXT J
1080    NEXT I
1090    !********************  BEGINING OF SEPERATE PULSE ANALYSIS***************
1100    Bad=0              ! NUMBER OF BAD PULSES ENCOUNTERED
1110    Avmax=0            ! AVERAGE MAXIMUM INTENSITY
1120    FOR P=1 TO Pulse           !MAIN LOOP START FOR EACH PULSE
1130    Max=0              ! MAXIMUM OF CURRENT PULSE
1140    Tstart=0           ! TIME START OF PULSE OCCURS
1150    !_____________________________________________________________________
1160    FOR I=0 TO 500   !SAVES TIME NOT TO LOOK TO 1024
1170               !  COULD TRIGGER ON RISING SLOPE. BUT NOISE MAY INHIBIT TRIGGER
1180    IF (I-Tstart)>200 THEN 1210   !IF DATA NOT 0 FOR 200 THEN PULSE STARTED
1190    IF A(P,I)>0 THEN 1210         !LOCATE START OF PULSE (TRIGGERS OFF 0)
1200    Tstart=I                      !TIME START OCCURED (SAMPLES)
1210    IF A(P,I)<Max THEN 1240       !FIND MAXIMUM INTENSITY
1220    Max=A(P,I)                    !MAXIMUM INTENSITY OF CURRENT PULSE (PIXELS)
1230    Tmax=I                        !TIME MAX OCCURED
1240    NEXT I !______________________________________________________________
1250    IF Max>.4*Maxval THEN 1300   !REJECTS PULSE IF UNDER 40% OF SAMPLE MAX
1260    Bad=Bad+1                     !COUNTS NUMBER OF BAD PULSES ENCONTERED
1270    Bad_pulse(P)=1 !ARRAY MARKS BAD PULSES SO WON'T BE INCLUDED IN STATISTICS
1280    PRINT "PULSE =".P." IS A BAD PULSE"
1290    GOTO 1800          !PROCESS NEXT PULSE
1300    IF Outopt=2 THEN 1460       ! OUTPUT OPTION 2 (ENERGY AND INTENSITY ONLY)
1310    Tedge=0                     ! INITIALIZE TAIL START TIME
1320    FOR I=Tmax+20 TO 800 !<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<< <<<<<<<<<<<<<<<<<
1330    IF A(P,I+11)>A(P,I+10) THEN 1350    !IF PULSE RISES THE , TAIL STARTED
1340    IF (A(P,I-20)-A(P,I))>=8 THEN 1370  !LOCATE SLOPE CHANGE FOR TAIL
1350    Tedge=I-10                          !TIME OF TAIL START
1360    GOTO 1380                           !TRIGGERS ON FIRST OCCURANCE OF SLOPE
1370    NEXT I                   !<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<
1380    IF Tstart>Tmax OR Tmax>Tedge OR Tstart>Tedge THEN 1260!REJECTS ON  TIMING
1390    Tend=1023  ! INITIALIZE END TIME OF PULSE
1400    FOR I=Tedge TO 1023  !////////////////////////////////////////////////////
1410    IF A(P,I)<>0 THEN 1440              !FINDS END OF PULSE (DROP TO ZERO)
1420    Tend=I                              !TIME END OCCURS
1430    GOTO 1450                           !TRIGGERS ON FIRST ZERO OCCURANCE
1440    NEXT I                   !/////////////////////////////////////////////////
1450    IF Tend<Tedge THEN 1260                     ! REJECTS ON TIMING ERROR
1460    Area(P)=0     ! INITIALIZE ENERGY AREA
                              CALCULATE SPIKE AND PULSE AREAS AND HALF WIDTH
1470    FOR I=Tstart TO Tend-1 !)))))))))))))))))))))))))))))))))))))))))))))))))
1480    Area(P)=Area(P)+A(P,I)*Interval
             !USES RECTANGLE METHOD TO DETERMINE PULSE ENERGY (INTEGRATES POWER)
1490    IF Outopt=2 THEN 1560   ! SPEEDS UP PROGRAM (ENERGY AND INTENSITY ONLY)
1500    IF I>Tedge THEN 1520    ! ENDS INTEGRATION AT BEGINNING OF TAIL
1510    Aspike(P)=Area(P)       ! ENERGY IN THE SPIKE
1520    IF I>Tmax OR A(P,I)>.5*Max THEN 1540  ! CONDITIONS FOR RISING HALF MAX
1530    T1=I                          !RISING HALF TIME
1540    IF I<Tmax OR A(P,I)<.5*Max THEN 1560  ! CONDITIONS FOR TRAILING HALF MAX
1550    T2=I                          !TRAILING HALF TIME
1560    NEXT I                   !)))))))))))))))))))))))))))))))))))))))))))))))))
1570    GOSUB Printout
1580    GOTO 1730
1590 Printout:  !+++++++++++++++++ PRINTOUT SEQUENCE ++++++++++++++++++++++++++++
1600    PRINT CHR$(132),"PULSE =";P;" ANAL[illegible]
1610    IF Outopt=2 THEN 1670
1620    PRINT "PULSE RISE TIME...... ";(Tmax[illegible]*Interval[illegible]
1630    PRINT "SPIKE HALF-WIDTH..... ";([illegible]
```

Figure A-2. Program listing (continued).

```
1640    PRINT "SPIKE DURATION....... ":(Tedge-Tstart)*Interval:"nS"
1650    PRINT "TOTAL DURATION....... ":(Tend-Tstart)*Interval:"nS"
1660    PRINT "SPIKE ENERGY......... ":DROUND(Aspike(P)*Constant*Range/124000,4):
"mJ"
1670    PRINT "TOTAL ENERGY......... ":DROUND(Area(P)*Constant*Range/124000,4):"m
J"
1680    Power=DROUND(Max*Constant*Range/128,4)
1690    PRINT "PEAK INTENSITY....... ":Power:"KW"
1700    PRINT
1710    RETURN !+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
1720    !::::::::::::::::::: STORES SIGNIFICANT TIMES FOR EACH PULSE :::::::::::
1730    Bad_pulse(P)=0              ! GOOD PULSE IF THIS FAR
1740    Parameter(1,P)=Tstart       ! TIME START OF PULSE OCCURED
1750    Parameter(2,P)=Tmax         ! TIME MAXIMUM INTENSITY OCCURED
1760    Parameter(3,P)=Tedge        ! TIME TAIL BEGINS (SPIKE ENDS)
1770    Parameter(4,P)=Tend         ! TIME PULSE ENDS
1780    Parameter(5,P)=T1           ! TIME OF RISING HALF INTENSITY
1790    Parameter(6,P)=T2           ! TIME OF TRAILING HALF INTENSITY
1800    NEXT P!*******************END OF SEPARATE PULSE ANALYSIS *************
**********************************************************************
1810    Avarea=0.   ! INITIALIZE AVERAGE AREA
1820    Avmax=0.    ! INITIALIZE AVERAGE MAXIMUM
1830    FOR I=1 TO Pulse!@@@@@@@@ DETERMINE STATISTICS OF ALL PULSES @@@@@@@@@@@
@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
1840    IF Bad_pulse(I)=1 THEN 1870
1850    Avmax=Avmax+A(I,Parameter(2,I))/(Pulse-Bad)  ! AVERAGE MAX INTENSITY
1860    Avarea=Avarea+Area(I)/(Pulse-Bad)            ! AVERAGE TOTAL ENERGY
1870    NEXT I
1880    S2=0         !INITIALIZE SD^2 OF INTENSITY
1890    S2area=0     !INITIALIZE SD^2 OF ENERGY
1900    FOR I=1 TO Pulse
1910    IF Bad_pulse(I)=1 THEN 1940      ! DON'T INCLUDE BAD PULSES IN STATISTICS
1920    S2=(A(I,Parameter(2,I))-Avmax)^2/(Pulse-Bad)+S2  ! SD^2 OF INTENSITY
1930    S2area=(Area(I)-Avarea)^2/(Pulse-Bad)+S2area     ! SD^2 OF ENERGY
1940    NEXT I
1950    S=DROUND(SQR(S2),4)          ! STANDARD DEVIATION OF INTENSTY (ROUNDED)
1960    Sarea=DROUND(SQR(S2area),5)  ! STANDARD DEVIATION OF ENERGY (ROUNDED)
1970    !@@@@@@@@@@@@@@@@@@@@ END OF STATISTICS CALCULATIONS @@@@@@@@@@@@@@@@@@@
@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
1980 Statistics:    PRINT CHR$(132),"STATISTICS EXCLUDING BAD PULSES",CHR$(128)
1990            GOSUB Off_keys
2000    PRINT "AVERAGE MAXIMUM INTENSITY=...........":DROUND(Avmax*Constant*Rang
e/128,5):"KW"
2010    PRINT "STANDARD DEVIATION OF INTENSITY=......":DROUND(S*Constant*Range/12
8,3):"KW"
2020    PRINT "AVERAGE ENERGY=.......................":DROUND(Avarea*Constant*Ran
ge/124000,4):"mJ"
2030    PRINT "STANDARD DEVIATION OF TOTAL ENERGY=...":DROUND(Sarea*Constant*Rang
e/124000,3):"mJ"
2040    PRINT
2050    PRINT "*****PHOTON CONSTANT=":Constant:"   PYRO CONSTANT=":Pyro_const:"**
***"
2060    PRINT "TOTAL OF ":Bad:" BAD PULSES OUT OF ":Pulse:"RECORDED"
2070    DISP " "
2080    IF Printer=701 THEN Keys
2090    PRINT CHR$(133),"PROGRAM NOW IN GRAPH MODE. USE KEYS TO CONTINUE",CHR$(12
8)
2100    PRINT
2110    !!!!!!!!!!!!!!!!!!!!!!!!! END OF PULSE CALCULATIONS !!!!!!!!!!!!!!!!!!!!!
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
```

Figure A-2. Program listing (continued).

```
2120 Keys:  ON KEY 0 LABEL "VIEW GRAPH" GOTO Screen
2130    ON KEY 5 LABEL "END PROGRAM" GOTO Finish
2140    ON KEY 6 LABEL "PARAMETERS" GOTO Params
2150    ON KEY 1 LABEL "SAMPLE STATS" GOTO Statistics
2160    ON KEY 1 LABEL "PLOT GRAPH" GOTO Hard
2170    ON KEY 2 LABEL "TOGGLE PRINTER" GOTO Toggle
2180    ON KEY 3 LABEL "STORE GRAPH" GOTO Disc
2190    ON KEY 4 LABEL "NEW SAMPLE" GOTO Start
2200    ON KEY 7 LABEL "CHANGE PHOTON" GOTO Const
2210    ON KEY 8 LABEL "CHANGE PYRO" GOTO Pyro
2220    ALPHA ON          ! TURNS ON ALPHA NUMERIC SCREEN
2230    ! LOOP REM
2240    GOTO 2230
2250 Screen: !***** PLOTS PULSE IN KW vs nS ON CURRENT PLOTTING DEVICE *********
**************************************************************************
2260    GOSUB [illegible]            ! SHUTS OFF USER DEFINED KEYS
2270    GRAPHICS OFF              ! SHUTS OFF GRAPHICS
2280    INPUT "WHICH PULSE NUMBER?",Pgraph
2290    GINIT                     ! INITIALIZE GRAPHICS
2300    GRAPHICS ON               ! TURN ON GRAPHICS
2310 Plot:  ALPHA OFF             ! SHUT OFF PRINTOUT (NOT GRAPHICS)
2320    VIEWPORT 0,[illegible],10,100  ! SET LIMITS OF GRAPHING AREA (DISPLAY UNITS)
2330    Xmin=-.5*Interval*1024 ! ALLOW ROOM FOR LABELING OF Y AXIS
2340    Axis_top=INT(Maxval*Range*Constant/1280+1)*10  ! ALTER AXES TO SAMPLE
2350    WINDOW Xmin,(Interval*1024+25*Interval),-.1*Axis_top,Axis_top !SETS RANGE
2360    CLIP 0,1024*Interval,0,Axis_top   ! DISABLES GRAPHICS OUTSIDE RANGES
2370    AXES 100,25,0,0,5,2,4             ! DRAWS AXES
2380    CLIP OFF                          ! ALLOWS GRAPHICS THROUGHOUT VIEWPORT
2390    CSIZE 2.5                         ! SETS SIZE OF GRAPHICS CHARACTERS
2400    !         NUMBERING OF THE X-AXIS____________________________________________

2410    LORG 6                  ! SETS ORIGIN OF GRAPHICS CHARACTERS(TOP CENTER)
2420    FOR I=0 TO 5000 STEP 1000
2430    MOVE I,0                ! LABELS TIME AXIS EVERY 1000 nS
2440    LABEL I
2450    NEXT I  !______________________________________________________________
2460    !        NUMBERING OF Y-AXIS^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^
2470    LORG 8    ! SETS ORIGIN OF GRAPHICS CHARACTERS (RIGHT CENTER)
2480    FOR I=0 TO Axis_top STEP 50
2490    MOVE 0,I           ! LABELS INTENSITY AXIS EVERY 50 KW
2500    LABEL I
2510    NEXT I !^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^^
2520    MOVE Interval*500,-.05*Axis_top   !  X AXIS LABEL LOCATION
2530    LORG 6    ! SETS ORIGN OF GRAPHICS CHARACTERS (TOP CENTER)
2540    CSIZE 3.1  ! SETS SIZE OF GRAPHICS CHARACTERS
2550    LABEL "TIME (nS)"
2560    MOVE Xmin,Axis_top/2          ! Y AXIS LABEL LOCATION
2570    DEG
2580    LDIR 90                       ! ROTATE GRAPHICS CHARACTERS 90 DEGREES
2590    LABEL "POWER (KW)"
2600    LDIR 0                        ! RETURN GRAPHICS CHARACTERS TO HORIZONTAL
2610    MOVE 0,0                      ! PLOTING PULSE
2620    FOR I=1 TO 1023
2630    DRAW I*Interval,A(Pgraph,I)*Range*Constant/128  ! DRAW PULSE(KW vs nS)
2640    NEXT I
2650    LORG 5                        !SET GRAPHICS CHARACTER ORIGIN (CENTER)
2660    CSIZE [illegible]             !SET SIZE OF GRAPHICS CHARACTERS
2670    FOR [illegible]               !MARKING SIGNIFICANT POINTS WITH "*"
[illegible] X=Param[illegible]Pgraph)
[illegible] IF X<[illegible] THEN 2740  ! IF OUT OF BOUNDS THEN DON'T MARK
```

Figure A-2. Program listing (continued).

```
2700   Y=A(Pgraph,X)*Range*Constant/128  ! CONVERTS TO KILOWATTS
2710   IF Y<0 OR Y>Axis_top THEN 2740    ! REJECT IF OFF GRAPH
2720   MOVE X*Interval,Y
2730   LABEL "*"
2740   NEXT J
2750   MOVE 0,0
2760   PLOTTER IS 3,"INTERNAL" ! SETS PLOTTER TO CRT IN CASE EXTERNAL
2770   GOTO Keys!********************** END OF GRAPH SECTION ****************
**************************************************************************
2780 Hard:     PLOTTER IS 705,"HPGL" !***********ENABLES EXTERNAL PLOTTER*******
2790           GOSUB Off_keys
2800    DISP "PREPARE PLOTTER AND CONTINUE"
2810    PAUSE
2820    GOTO Plot !*********************************************************
2830 Toggle: !******** TOGGLES PRINT DEVICE (INTERNAL/EXTERNAL)****************
2840                 GOSUB Off_keys
2850                 IF Printer=701 THEN 2900
2860                 PRINTER IS 701
2870                 Printer=701
2880                 DISP "PRINTER IS 701"
2890                 GOTO 2930
2900                 Printer=1
2910                 PRINTER IS 1
2920                 DISP "PRINTER IS 1"
2930                 GOTO Keys !********************************************
2940 Params:!*************** PRINTS OUT SAMPLE STATS WITH CURRENT CONSTANTS*****
2945          GOSUB Off_keys
2950          INPUT "INPUT THE PULSE YOU WANT TO SEE STATS ON",P
2960          IF P<=Pulse AND P>0 THEN 2970
2961          DISP "SORRY...ILLEGAL PULSE NUMBER. MUST BE BETWEEN 0 AND ";Pulse
2962          GOTO 3050
2970          Tstart=Parameter(1,P)            ! SETS PARAMETERS FROM
2980          Tmax=Parameter(2,P)              ! PARAMETER ARRAY
2990          Tedge=Parameter(3,P)
3000          Tend=Parameter(4,P)
3010          T1=Parameter(5,P)
3020          T2=Parameter(6,P)
3030          Max=A(P,Tmax)
3040          GOSUB Printout
3050          GOTO Keys !***************************************************
3060 Disc:  !*****************STORES GRAPH ON DISC ****************************
3070   GOSUB Off_keys
3080   INPUT "ENTER THE FILE TO STORE PULSE ON",D$
3090   INPUT "WHAT PULSE DO YOU WANT TO STORE?",Store_pulse
3100   MASS STORAGE IS ":INTERNAL,4,1"   ! MASS STORAGE DEVICE LEFT DISC DRIVE
3110   CREATE BDAT D$,2051,8             ! CREATE DATA FILE OF APROPRIATE LENGTH
3120   ASSIGN @Path TO D$                ! ASSIGN OUTPUT PATH TO DATA FILE
3130   FOR I=1 TO N
3140   Tempy(I)=A(Store_pulse,I)*Constant*Range/128 !DEFINE TEMPORARY ARRAY (KW)
3150   NEXT I
3160   OUTPUT @Path;1020     ! STORE NUMBER OF POINTS FOR GRAPHICS PROGRAM
3170   OUTPUT @Path;Interval ! STORE nS PER ARRAY ELEMENT
3180   OUTPUT @Path;Tempy(*) ! STORE ARRAY (KW) UNFORMATTED
3190    MASS STORAGE IS ":INTERNAL"  ! MASS STORAGE DEVICE RIGHT DISC DRIVE
3200    PRINT "PULSE STORED (KW vs. nS) ON FILE NAMED ";D$
3210   GOTO Keys !*********************************************************
3220 Const: !*****************CHANGES PHOTON DRAG CONSTANT*******************
3230          GOSUB Off_keys
3240          DISP "USE KEYS TO CHOOSE METHOD OF ENERGY DETERMINATION"
3250          ON KEY 1 LABEL "CALORIMETER" GOTO 3280
```

Figure A-2. Program listing (continued).

```
3260        ON KEY 2 LABEL "PYRO ELECT." GOTO 3330
3270        GOTO 3270
3280        GOSUB Off_keys
3290        INPUT "ENTER AVERAGE CALORIMETER READING IN mJ",Millijoules
3300        Constant=Constant*Millijoules/(Avarea*Constant*Range/124000)
3310        PRINT "NEW PHOTON DRAG CONSTANT=";DROUND(Constant,5)
3320        GOTO Keys
3330        GOSUB Off_keys
3340        INPUT "HOW MANY ENERGIES DO YOU WANT TO TAKE",Pyro_rep
3350   DISP "CHANGE INPUT TO PYRO AND CHANGE TIMEBASE TO FIND MAXIMUM,THEN <CONT
INUE>"
3360   PAUSE
3370   DISP "READY FOR PULSE FROM PYRO"
3380   Ave_pyro=0      ! INITIALIZE AVERAGE PYRO READING
3390   FOR J=1 TO Pyro_rep
3400   OUTPUT 704:8    ! ARMS THE 6500 DIGITIZER
3410   OUTPUT 704;11   ! PUTS THE 6500 INTO OUTPUT MODE
3420   ENTER 704 USING "#,B":B(*) ! ENTER BUFFER ARRAY UNFORMATTED
3430   OUTPUT 704:0    ! CLEARS THE 6500 OF DIGITAL OUTPUT
3440   DISP J;" OF ";Pyro_rep;" SHOTS"
3450   Max_pyro=0
3460   FOR I=1 TO 500
3470   IF B(I)<=127 THEN 3490          !CONVERT TO WORD 2'S COMPLEMENT
3480   B(I)=B(I)-256                   !      FROM BYTE 2'S COMPLEMENT
3490   B(I)=B(I)-Dc_offset             ! ACCOUNT FOR DC OFFSET
3500   IF Max_pyro>B(I) THEN 3520      ! FINDS THE MAXIMUM VOLTAGE
3510   Max_pyro=B(I)
3520   NEXT I
3530    Ave_pyro=Max_pyro/Pyro_rep+Ave_pyro  ! FINDS THE AVERAGE MAXIMUM VOLTAGE
3540   NEXT J
3550   Energy=Ave_pyro*Range*Pyro_const/128  ! FINDS THE ENERGY FROM PYRO CONST
3560   Constant=DROUND(Energy/(Avarea*Range/128000),6) !NEW PHOTON DRAG CONSTANT
3570   PRINT "NEW CONSTANT=";Constant
3580   GOTO Keys !***********************************************************
3590 Off_keys:    ! SHUTS OFF USER DEFINED KEYS**********************************
                   OTHERWISE PROGRAM MAY BRANCH IN MIDDLE OF SUBROUTINE
3600             OFF KEY 0
3610             OFF KEY 1
3620             OFF KEY 2
3630             OFF KEY 3
3640             OFF KEY 4
3650             OFF KEY 5
3660             OFF KEY 6
3670             OFF KEY 7
3680             OFF KEY 8
3690             OFF KEY 9
3700  RETURN !**************************************************************
3710 Pyro: !     DETERMINES NEW PYROELECTRIC CONSTANT****************************
3720       GOSUB Off_keys
3730       PRINT "OLD PYRO CONSTANT=";Pyro_const
3740       PRINT "ENTER PYROELECTRIC PULSE THRU DIGITIZER"
3750       INPUT "HOW MANY SHOTS DO YOU WANT TO TAKE",Shots
3760       Avmaxvolt=0
3770       DISP "READY FOR DIGITIZER INPUT. HIT <CONTINUE> WHEN READY"
3780       PAUSE
3790       FOR J=1 TO Shots
3800       OUTPUT 704:8       ! ARMS THE 6500 DIGITIZER
3810       OUTPUT 704:11      ! PUTS THE 6500 INTO OUTPUT MODE
3820       ENTER 704 USING "#,B":B(*)  ! ENTERS BUFFER ARRAY FROM 6500
           OUTPUT 704:0       ! CLEARS THE 6500 OF OUTPUT MODE
```

Figure A-2. Program listing (continued).

```
3840        Maxvolt=0
3850        FOR I=1 TO 500
3860        IF B(I)<=127 THEN 3880          !CONVERT TO WORD 2'S COMPLEMENT
3870        B(I)=B(I)-256                   !       FROM BYTE 2'S COMPLEMENT
3880        B(I)=B(I)-Dc_offset             ! ACCOUNT FOR DC OFFSET
3890        IF B(I)<Maxvolt THEN 3910       ! FINDS MAXIMUM PYRO VOLTAGE
3900        Maxvolt=B(I)
3910        NEXT I
3920        DISP J;"OF";Shots;"SHOTS TO BE TAKEN"
3930        Avmaxvolt=Maxvolt/Shots+Avmaxvolt  ! FINDS AVERAGE MAX PYRO VOLTAGE
3940        NEXT J
3950        INPUT "ENTER ENERGY READING FROM CALORIMETER IN MILIJOULES ",Milijoul
es
3960        Pyro_const=DROUND(Milijoules/(Avmaxvolt*Range/128),5)
3970        PRINT "NEW PYRO CONSTANT=";Pyro_const ! NEW PYRO CONST. CALIBRATED TO
                                                    CALORIMETER
3980    ON ERROR GOTO 4010
3990    Constant=DROUND(Milijoules/(Avarea*Range/128000),6)!NEW PHOTON DRAG CONST
4000    GOTO 4020
4010    PRINT "NO ENERGY READINGS AVAILABLE TO CHANGE PHOTON DRAG CONSTANT"
4020    OFF ERROR
4030    GOTO Keys!*************************************************************
4040 Finish:    PRINTER IS 1
4041            PRINT CHR$(12)
4050            GRAPHICS OFF
4060            DISP "HIT <CONTINUE> TO LOAD PROGRAM DIRECTORY"
4070            PAUSE
4080            LOAD "AUTOST"
4090            END
```

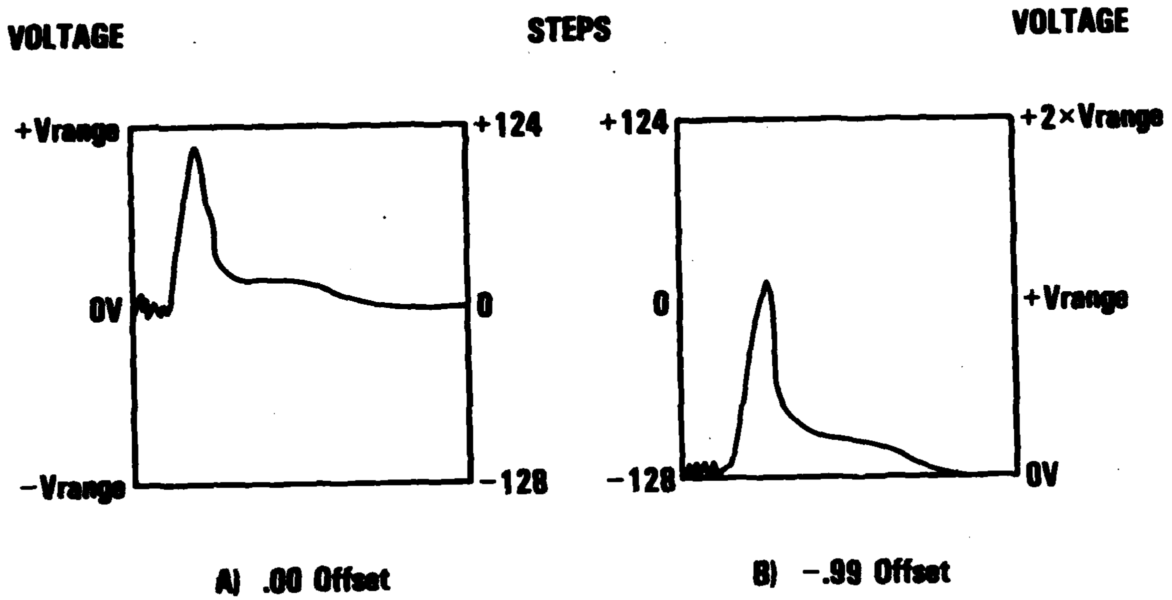

Figure A-3. Point of the OV line.

Y OUTPUTS

Address	0-1023	1024		1025		1026	
Data bits Out	Data	Input Range		Offset		Sample Interval	
Y_7	MSB	Low:DC	High:AC	Low:+	High:-	Low:INT	High:EXT
Y_6		0.25		64		MS	
Y_5		0.50		32		MS	
Y_4		1.0		16		NS	
Y_3		2.0		8		8	
Y_2	LSB	5.0		4		4	
Y_1	LOW	LOW		2		2	
Y_0	LOW	LOW		1		1	
Logic	POS. TRUE	NEG. TRUE		POS. TRUE		NEG. TRUE	
Code Defin.	2's Comp	1 of 5 AC/DC		% Full Scale Signed Binary		Weighing: 0=2 1=5 2=10 3=20	 4=50 5=100 6=200 7=500 8=1000

Figure A-4. Readings from digitizer.

c. Input Range (lines 360 to 400). In this case, only bits 2 to 6 are of interest. Since these bits are negative true logic, the low bit corresponds to the input range. Line 320 calculates the input range for Y_3 to Y_6. The exception to the equation (Y_2) is trapped in line 400.

d. Offset. The offset is calculated in line 360. The binary AND of the offset byte with 127 masks out the sign bit to give the absolute offset in percent. Divide by 100 to get the fraction of input range. Multiply by $-1 \Lambda (Y_7)$ to account for sign.

e. Interval (lines 290 to 350). Bits Y_0 to Y_3 are of interest here. For this application, internal time base in nanoseconds is assumed. Line 270 determines the weighing number. The binary AND of 15 and the interval byte gives only Y_0 to Y_3. The EX-OR of 15 and Y_0 to Y_3 gives the desired positive true weighing factor. Since there is no simple equation to generate the interval weight, a loop is used to read the proper weighing factor. An array could be used, but would require more memory.

f. Offset Check (lines 540 to 610). There is no simple way to calculate the step offset from the percent offset to better than an interval of 4 (percent). To eliminate this possible 3-percent error in voltage, the program prompts the user to arm and trigger the digitizer with O V input to check the calculated step offset with the true screen offset. If they differ by more than 4 (percent), the program re-prompts the user. If they are within 4 (percent), the true screen offset is used in the program.

3. Array Definitions and Pulse Data Entry (lines 700 to 890).

a. Integer Arrays A(120, 1023). Holds pulses in interval step units.

- Room for 120 pulses with 1024 samples each.
- **B(1026).** Buffer array for fast data entry by unformatted ENTER statement.
- **Parameter (6,120).** Holds the times of the six important events of each of 120 pulses.
- **Bad pulse (120).** Marks the bad pulses to be excluded from statistical analysis.

b. Real Arrays Area (120). Area under pulse in interval step units.

- **Aspike (120).** Area under spike in interval step units.

- **Tempy (1023).** Temporary storage for pulse intensity in kW used for pulse disc storage.

NOTE: Most calculations and storage are left in interval step units to reduce run time and memory use. Conversion to proper units occurs only for I/O.

c. Pulse Data Entry. The HP 9836 computer uses an HPIB to interface with the 6500 digitizer. The digitizer address in this program is 704. There are four digitizer I/O commands necessary for this program.

- **OUTPUT 704;8.** Arms the 6500 Digitizer (single sweep mode).

- **OUTPUT 704;11.** Puts the 6500 in output mode.

The 6500 now waits for a trigger pulse and then records waveform data.

- **ENTER 704 USING "#,B";B(*).** Enters the data from the 6500 into a buffer array (unformatted). This buffer is necessary because an unformatted read into a two-dimensional array is not allowed, and single element entry into a two-dimensional array takes much longer.

- **OUTPUT 704;0.** Clears the 6500 of digital output.

The buffer array is now transferred into the two-dimensional A(120, 1023) array.

NOTE: Data stored in the A(120,1023) array is in 2's complement bytes. No further processing is done at this time, because pulse rate is already limited to 0.7 Hz.

4. Convert to Word 2's Complement and Subtract DC Offset (lines 1000 to 1080). This program segment converts the byte 2's complement data from the digitizer to the word 2's complement used by the computer. The DC offset is subtracted from each pixel (see Block 2). The pulse is also rectified by taking the absolute value, so that either inverting or non-inverting amplifiers can be used after the detector.

5. Find Maximum of all Pulses (lines 1050 to 1060). The maximum intensity of the sample of pulses is found, so that any pulses below 40 percent of this value can be rejected. This maximum is also used to determine the intensity range for graphing the sample pulses.

6. Find Pulse Start Time and Maximum Value (lines 1160 to 1240). Ideally, the start of the pulse should be recognized by a change in slope. However, noise frequency limits this option. The method used in the program triggers from zero. The program keeps track of

where the waveform last hit zero (line 1200). If the waveform does not return to zero after 200 sample units, the last zero is considered the pulse start (see Figure A-5). This step of 200 units may have to be decreased for short pulses or long time bases. The program, then, records the maximum intensity (Max) and the corresponding time T_{max}.

7. Forty Percent Reject Level (lines 1250 to 1290.) **If a pulse maximum (Max) is less than 40 percent of the sample maximum (Maxval), then the pulse is called "bad" and is not included in statistical pulse analysis. This rejection eliminates false triggers caused by external corona discharge or turning detectors on or off.**

8. Locate Spike End From Slope Change (lines 1320 to 1370). **The spike and (Tedge) is defined at the point where the slope of the waveform suddenly becomes less negative and rises above a certain value. This equation is in line 1360 and may have to be tailored for different time bases. A pulse can be rejected at this point, if the timing sequence is incorrect (line 1400).**

9. Locate Pulse End (lines 1400 to 1440). **The pulse end is defined as the first point after the spike end where the waveform drops to zero T_{end}. If the waveform does not drop to zero, the pulse is rejected.**

10. Find Spike Energies and Half Widths (lines 1470 to 1560).

$$E = \frac{Kpd*Vrange*}{124000} \int_{T_{start}}^{T_{end}} V_{pd}\, dt.$$

Since the intensity is a stepped function, rectangular integration is used to determine pulse energy. This segment, also, finds T_1 and T_2 to determine the pulse half width (Figure A-5).

11. Significant Parameters Stored (lines 1720 to 1790). **The times at which the six significant events occur for each pulse are stored in the Parameter (6,120) array. These times are used later to find corresponding intensities and temporal characteristics.**

12. Print Significant Parameters (lines 1590 to 1710). **Prints single pulse statistics to current printing device. Converts to kW, mJ, and ns on printout using current photon drag constant.**

13. Calculate Sample Statistics (lines 1810 to 1970). **This program section looks at all pulses entered. If the pulse is bad because of low intensity or a timing error, it is not included in the analysis. Energy and maximum intensity averages, and standard deviations are calculated for the group of pulses.**

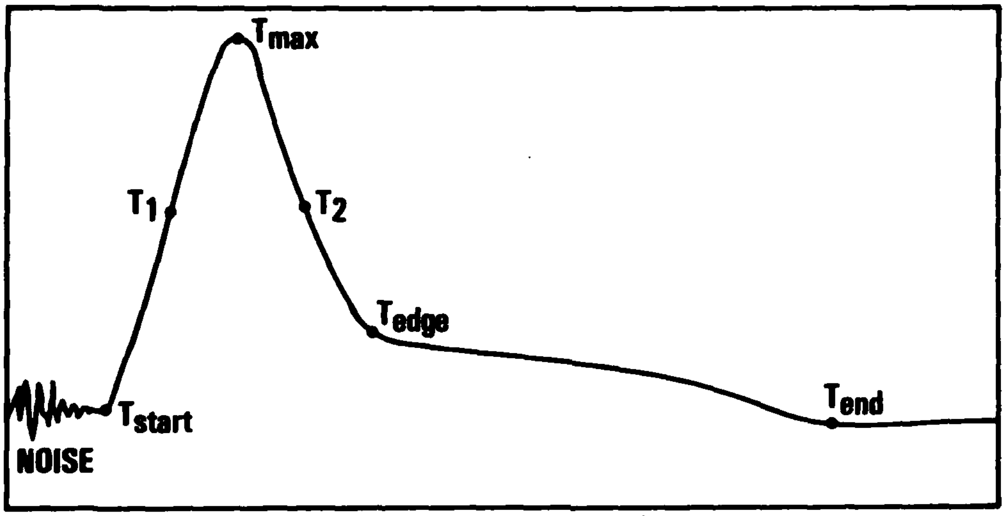

Figure A-5. Pulse event time markers.

14. Key X (lines 2120 to 2240). At this point all major calculations are completed. The photon drag or pyroelectric constants can be changed, or data can be sent to external output devices. By hitting a user-defined key, the program executes a *subprogram*, *returns* to this spot, and waits for another key to be depressed. Keys are disabled during subprograms so output can be completed.

15. Key 0 "VIEW GRAPH" (lines 2250 to 2770). This key produces a graph of power vs. time of the desired pulse number on the computer CRT. The top of the power axis is determined by the maximum sample intensity. The significant points of the laser pulse are marked with a "*" for reference. The program then returns to Key X.

16. Key 1 "PLOT GRAPH" (lines 2780 to 2820, 2310 to 2770). This key transfers control to an external plotter and, then, branches into Key 0 to produce a plot of power vs. time on paper.

17. Key 2 "TOGGLE PRINTER" (lines 2830 to 2930). This key is a fast, one step way of changing the printer from internal to external or vice versa (i.e., CRT display or hard copy). Otherwise, the program would have to be stopped, a command executed and, then, the program continued.

18. Key 3 "STORE GRAPH" (lines 3060 to 3210). This key stores on disc the pulse intensity in kW. The number of points and the number of nanoseconds per array index is also stored. The format of the data file is compatible with a graphics program to make presentation quality graphs.

19. Key 4 "NEW SAMPLE" (line 2190.) This key prepares for a new pulse sample but does not reinitialize the photon drag and pyroelectric constants. The digitizer control settings can be changed for the new sample. Program continues on line 80.

20. Key 5 "PARAMETERS" (lines 2940 to 3050). This key initializes the time markers to those of the desired pulse from the parameter (6,120) array. The program then prints out the pulse rise time, half width, spike duration, total duration, spike energy, total energy, and peak intensity using the current photon drag constant. This printout is sent to the current printing device as specified by Key 2.

21. Key 6 "SAMPLE STATS" (lines 1980 to 2070). This key prints out the pulse sample averages, and standard deviations of pulse energy and maximum intensity on the current printing device. The energies and intensities are computed using the current photon drag and pyroelectric constants which are, also, printed out.

22. Key 7 "CHANGE PHOTON" (lines 3220 to 3580). This key is used to change the photon drag constant. If the average energy computed by the program does not match a calorimeter reading, the photon drag detector constant can be changed by entering a calorimeter reading or by using the pyroelectric detector as a calorimeter. The photon drag constant is in units of kW/V.

23. Key 8 "CHANGE PYRO" (lines 3710 to 4030). This key calculates a new pyroelectric constant in mJ/V. The average maximum voltage from the pyroelectric detector through the 6500 digitizer is determined. This average voltage is proportional to the average energy which is entered in mJ to determine the constant in mJ/V of the pyroelectric detector. The pyroelectric detector can now be used as a standard to calibrate the photon drag detector.

24. Key 9 "END PROGRAM" (lines 4040 to 4090). This key reloads the disc program directory.

General Comments. Some of the algorithms used in this program sacrifice speed in order to reduce memory requirements. In the current program, pulse analysis is limited to 120 pulses. This limit could be considerably increased if comments or unneeded segments are eliminated. LOAD SUB and PURGE SUB commands could, also, be used to load and purge program segments as they are needed on the run.

For lifetime tests, a loop could be put in Section 3 (Pulse Data Entry) to record every 10th or 100th pulse to increase sample range.

All pulse arrays in this program are kept in step units until the time of output. This is done for several reasons. The array as integer step units takes up less room than the real array converted to kW. The processing of integer numbers, also, takes less time than floating point operations. Another advantage is that when the photon drag constant is changed, none of the pulse storage arrays have to be accessed since conversion is done at output.

In some cases, program efficiency is given up for clarity. After the program is understood, efficiency can be improved by removing comments or I/O prompts and combining lines.

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